Breeding for Drought Resistance

Features of Drought

In Bangladesh, problems of drought, salinity and alkalinity are of major concern among environmental stresses. Drought refers to the condition of soil moisture deficiency or water scarcity. Soil drought is more common in the arid and semi arid tropics and in the areas of steep slope. Thus desert areas are more prone to drought conditions. The ability of crop plants to grow, develop and reproduce normally under moisture deficit conditions is referred to as drought resistance. In other words, drought resistance refers to survival of plants under water deficit or scarcity conditions without injury. Improvement in the drought tolerance ability of a plant is known as drought hardening. Main features of drought are given below:

1. Drought is characterized with soil moisture deficit or low soil moisture.

2. Arid and semi-arid areas are more prone to drought than humid zones. About 36% of the land area constitute arid and semi arid zones.

3. Drought leads to reduction in both yield and quality of economic product in crop plants. It has adverse effects on plant growth and development.

4. Drought damages chloroplasts and lowers output of the photosynthetic apparatus.

5. There is an increase in proline level in the leaves of plants which are subjected to drought, Proline level can be used as an indicator of water stress, but not as a measure of drought resistance.

6. The occurrence of drought depends on the amount and distribution pattern of rainfall. If the rainfall is adequate and well distributed over the crop season, there are less chance of drought. On the other hand , when rainfall is erratic there are more chances of drought. Soil type and topography also affect drought.

7. Drought resistance is a genetically controlled physiological property of plant species. Resistance to drought is associated with various morphological and physiological features of the plant.

8. Xerophytic plants are more resistant to drought than mesophytes.

9. There is an increase in abscisic acid content in leaves of barley, and in ethylene level in cotton and wheat under drought conditions.

Drought Resistance

It is the ability of a plant to maintain favorable water balance and turgidity even exposed to drought conditions there by avoiding stress and its consequences. Stress avoidance due to morphological, anatomical characteristics which themselves are the consequences of the physiological processes induced by drought these zerophytic characteristics are quantitative and vary according to environmental conditions.

A favorable water balance under drought conditions can be achieved by transpiration before as soon as stress is experienced. These are called "water savers" or Accelerating water uptake sufficiently so as to replenish the lost water called as "water spenders"

Plant characters associated with drought resistance

Morphological & Anatomical	Grain yield; maximum root length, Root volume, Root dry weight, Root thickness, Root surface area, above ground biomass, Harvest index, Leaf drying, Leaf tip firing, Delay in flowering, Aerenchyma, Leaf pubescence.
Phenological	Earliness, Delay in flowering, Anthesis, Silking interval, Seedling vigor, Weed competitiveness, Photosensitivity, Perennially.
Physiological & Biochemical	Osmotic adjustment, Carbon isotopes discrimination, Stomatal conductance, Remobilization of stem reserves, Specific leaf weight, ABA electrolyte leakage, Leaf rolling, Tip firing, Stay green, Epicuticular wax, Feed foreword response to stress.
Oxygen scavenging	Heat shock proteins, Cell wall proteins, Leaf water potential, Water use efficiency, Aquaporins, Nitrogen use efficiency, Dehydrins.

Mechanisms of Drought Resistance

There are four different mechanisms which help in survival of plants under moisture deficit conditions. There are:

1) Drought escape.

2) Drought avoidance.

3) Drought tolerance.

4) Drought resistance.

The last one refers to true drought resistance. These are briefly described below:

1. Drought Escape

The simplest way of survival under drought conditions is to escape drought. Generally, drought occurs either in the mid or late-crop season. Drought escape is most common in case of plants grown in desert regions. They complete their life cycles in 4 to 6 weeks. Drought

escape also plays an important role in some crop plants. For Example, yields of early varieties of wheat, sorghum, maize, and rice are less affected by severe drought than late maturing ones. All these crops have determinate growth habit. In spring wheat, late maturing varieties give higher yield than early types especially when drought occurs early in the season and is over before anthesis.

2. Drought Avoidance

Drought avoidance refers to ability of the plant to maintain a favourable internal water balance under moisture stress. In other words, plants which avoid drought retain high water contents in their tissues. Drought avoidance can permit a longer growth period in the crop through reduced water use or increased water uptake. However, drought avoidance leads to reduction in photosynthesis and thereby reduction in the growth of aerial parts. It leads to increase in root development and therefore, is more important than drought tolerance. In cereals, drought avoidance operates during vegetative phase, while tolerance operates during reproductive phase. Drought avoidance mechanisms are of two types. First those which reduce water loss through transpiration. Such features include stomatal characteristics and shape, size and orientation of leaves. The second, those which maintain water uptake during drought period.

3. Drought Tolerance

The ability of crop plants to withstand low tissue water content is referred to as drought tolerance. Drought tolerance is more desirable because the crop can produce more yield at lower water potential. In cereals, drought tolerance generally operates during reproductive phase. Tolerant cultivars exhibit better germination, seedling growth and photosynthesis. In Sorghum, a drought resistant line exhibited higher photosynthetic rate at leaf water potential than a less drought resistant line. Drought tolerance differs from drought avoidance in several aspects.

4. Drought Resistance

Drought resistance is the sum of drought avoidance and drought tolerance. In other words, drought resistance refers to the ability of crop plants to give good yield under moisture deficit conditions. Drought resistance is measured in terms of various mechanisms associated with drought tolerance and yield under soil moisture deficit. In winter wheat, both avoidance and tolerance features are important for drought resistance.

Morphological Characters associated with drought resistance

Drought resistance is associated with various morphological and physiological features or factors of crop plants. Morphological characters which are associated with drought resistance included earliness, shape, size and structure of stomata, size, number and orientation of leaves, presence of cuticle, Waxiness on leaf lamina and stem, rooting pattern, growth habit etc. They are discussed below-

1. Earliness

Earliness is a desirable character which leads to drought escape in many crops. For example, in wheat, sorghum, maize, and rice yield of early maturing varieties is less affected by severe drought than late maturing varieties.

2. Stomatal Features

Sunken, small size and less number of stomata are associated with drought resistance. Control of stomatal aperture is important in drought resistance. The rapid closing of stomata during development of drought helps in maintaining higher water potential in the tissues by reducing transpiration rate and thus resulting in drought avoidance. The stomatal aperature is measured with the help of porometers. Drought resistant genotypes have rapid closing habit of stomata. Porometers are of two types, viz.

1) Viscous flow porometers which measure out flow rate of air through the leaf.

2) Diffusive flow porometers which measures the rate of diffusion of water vapour out of the leaf.

Now infrared thermometers are used to measure leaf water status and stomatal activity. Leaves with closed stomata will exhibit higher temperature than those with open stomata. Leaves with open stomata have cooling effect due to water loss through transpiration.

3. Leaf Characters

Cuticular thickness and Waxiness of leaf surface help in reducing transpiration. These characters are genetically controlled. Leaf rolling is an indicator of stress. It can also serve as drought avoidance mechanisms. Leaf rolling reduced transpiration from 46 to 63% in some grasses of Mediterranean region. In cotton, small and thick leaves are associated with drought resistance. Leaf hairiness lowers the leaf temperature and thus reduces transpiration. In barley, light green and golden leaves reflect more light than dark green leaves and thus remain cooler. The genotypes which reflect more light have more cooling effect resulting in reduction of transpiration.

4. Rooting Patterns

Increase in depth, width and branching of root systems leads to decrease in plant water stress. Generally, deep rooted plants exhibit greater drought avoidance than shallow rooted ones. Wheat cultivars that produce greatest root mass under drought conditions are important in breeding for drought resistance if the depth is more than 60 cm. Breeding for root patterns associated with drought resistance has been successful in several crops such as soft and hard wheat, barley, corn and sunflower. Two drought resistant cultivars of durum wheat have been developed in Canada through the use of extensive root system. The new varieties combine deep root system, good grain quality and high yield. seedling root growth is an indication of root growth at maturity.

5. Growth Habit

In upland cotton, interminate genotypes yielded more than determinate genotypes in a semiarid environment. Interminate plants produce flowers throughout the growing seasons whenever sufficient moisture is availability. This is not possible in case of determinate genotype.

6. Awns

In wheat and barley, presence of awns appears to be associated with high yield under drought conditions. The increase in yield from awns results due to increase in seed size. Awns play important role in growth and development of seeds through increase in photosynthetic surface of spike.

7. High tiller survival

Comparison of old and new varieties have shown that under drought older varieties over produce tillers many of which fall to set grain while modern drought tolerant lines produce fewer tillers most of which survive.

8. Stay green

The trait may indicate the presence of drought avoidance mechanism but probably does not contribute to yield if there is no water left in the soil profile by the end of the cycle to support leaf gas exchange. It may be detrimental, if it indicates lack of ability to remobilize stem reserves. However, research in sorghum has indicate that stay green is associated with higher leaf chlorophyll content at all stages of development and both were associated with improved yield and transpiration efficiency under drought.

9. Large seed size

Help emergence, early ground cover and initial biomass.

10. Long coleoptiles

For emergence from deep sowing.

11. Early ground cover

Thinner, wider leaves and a more prostrate growth habit help to increase ground cover thus conserving soil moisture and potentially increasing radiation use efficiency.

12. Good capacity for stem reserves and remobilization.

13. High spike photosynthesis capacity.

14. High pre-Anthesis biomass.

Physiological features associated with drought resistance

Various physiological characters which are related to drought resistance are photosynthetic rate, transpiration rate, osmotic concentration etc. These factors are briefly discussed below:

1. Osmotic adjustment

As a plant, detect a water deficit stress, it may accumulate a variety of osmotically active compounds such as amino acids, sugars and ion inside its cells, resulting in a lower of the cell osmotic potential. Water present in intercellular spaces then flows towards the inside of those cells. This process called "Osmotic adjustment", was proposed as a potential factor that could enable plants to maintain turgor and survive better at low water status. It has however been argued that osmotic adjustment probably does not allow the plant to draw much extra water from the soil and that is could come at a cost in yield potential.

2. Cell membrane stability

The ability to survive dehydration is influenced by a cells ability to survive at reduced water content. This can be considered complementary to Osmotic adjustment because both traits will help maintain leaf growth during drought. Crop varieties differ in dehydration tolerance and an important factor for such differences in the capacity of the cell membrane to prevent electrolyte leakage at decreasing water content or cell membrane stability (CMS). The maintainence of membrane function is assumed to mean that cell activity is also maintained. Measurements of CMS have been used in different crops and are known to be correlated with yields under high temperature and possibly under drought stress.

3. Epicuticular wax

In sorghum, drought resistance is a trait that is highly correlated with the thickness of the Epicuticular wax layer. Experiments have demonstrated that rice varieties with a thick cuticle layer retain their leaf turgor for longer periods of time after the onset of a water stress.

4. Partitioning and stem reserve mobilization

As photosynthesis becomes inhibited by drought, the grain filling process becomes increasingly reliant on stem reserve Utilization. 72 numerous studies have reported that stem reserve mobilization capacity is related to yield under water stress in wheat, rice. A few studies also indicated that this mechanism maintained grain yield under water stress at grain filling stage. The drought tolerance mechanism is stimulated by a decrease in gibberellic acid concentration and an increase in abscisic acid concentration.

5. Seedlings drought traits

For emergence from deep sowing (to exploit dry upper soil), this practiced to help seedlings reach the receding moisture profile and to avoid high soil surface temperatures which inhibit germination. Screening at these stage provides practical advantage specially when managing large amount of germplasms.

6. Accumulation of ABA

The benefit of ABA accumulation under drought has been demonstrated (Innes et al. 1984). It appears to pre-adapt plants to stress by reducing stomatal conductance, rates of cell division, organ size and increasing development rate. However, high ABA can also result in sterility problems since high ABA levels may abort developing florets.

Measurement of Drought Resistance in Plant Breeding

Various procedures are used for measuring drought resistance in crop plants. The most commonly used procedures include:

1) Leaf water retention.
2) Photosynthesis.
3) Yield performance.
4) Root lengths of seedlings.

These techniques can be used for large scale screening of segregating populations in breeding programme.

1. Leaf Water Retention

In this method leaves are excited from the plant and are allowed to dry. The slower drying

genotypes are considered as drought tolerant. In other words, the high water retainer genotypes are considered as drought tolerant. The cut leaf method was used in wheat, barley and oats. In wheat, two varieties Pelissier and Pitic 62 were significantly better water retainers when leaves were excised from three week old plants. These two varieties are highly resistant to drought. Some investigators use tissue water potential as an index of water stress under drought conditions. The tissue water potential is measured with the help of thermocouple psychrometer. The portable field psychrometer is widely use for measuring drought resistance in segregating populations.

2. Rate of Photosynthesis

The rate of photosynthesis during and after moisture stress is an important index of drought resistance. In wheat, Pitic 62 (a drought resistant variety) exhibited high photosynthetic rate under drought conditions in several tests. Now portable non-destructive photosynthesis analyzers are available which can be used in the fields for large scale screening of germplasm as well as segregating populations in standing crops. The genotypes which have high photosynthetic rate under moisture stress are considered as drought resistant, because such genotypes give higher yield than those having low photosynthetic rate. A simple portable photosynthesis analyser made it possible to measure photosynthesis of many plants within a short time. Now photosynthesis is used as a criterion to select for drought resistance.

3. Yield Performance

Superior yield performance under moisture stress conditions is an important and reliable index of drought tolerance. The yield tests should be conducted in drought prone areas at several locations or for several years. These will help in identification of genotypes with drought resistance and also in the elimination of drought susceptible lines. The yield test should be conducted under both field as well as glass house conditions. Moreover, large number of populations should be grown. This will enhance chances of obtaining superior drought resistant genotype.

4. Root Length of Seedlings

The root length during seedling stage is also used a measure of drought resistance. In wheat during root length of 5-7 days old seedlings grown in sand was related to root mass at maturity. In a more recent study it was observed that root mass after 30 days was reliable index of root mass at maturity. Thus those genotypes which have longest root during seedlings stage also exhibit extensive root system at maturity. This is a simple and quick method of measuring drought resistance in each crop season. Moreover, after screening superior plants can be replanted and grown to maturity. Some workers use hydroponics tank to measure the root growth of seedlings. (Sullivan and Rose, 1977).

In rice, the force required to pull out the seedlings from paddy soil is used as a measures of

drought tolerance. The force required is correlated with root weight, branching and number. This technique may be used for large scale screening of rice populations for drought resistance (O Toole and Soemartono, 1981).

Drought Resistance Mechanism

The ability of a crop species or variety to grow and yield satisfactorily in areas subjected to periodic water deficits is termed as drought resistance.

Types of drought resistance

1. Drought escape : The ability of a plant to complete the life cycle before serious soil and plant water deficits develop.

2. Drought tolerance with high tissue water potential : The ability of the plant to endure periods of drought whilst maintaining a high plant water stress. This is also referred to as drought avoidance (Levitt, 1972).

3. Drought tolerance with low tissue water potential: The ability of the plant to endure periods without significant rainfall and to endure low tissue water potential.

Table 15.1 - Mechanisms of drought resistance (after Jones et al. 1981)

1.	Drought escape	
	(a)	Rapid phenological development
	(b)	Developmental plasticity
2.	Drought tolerance with low tissue water potential	
	(a)	Maintenance of turgor
	(i)	Solute accumulation
	(ii)	increase in elasticity
	(b)	Dessication tolerance
	(i)	protoplasmic resistance
3.	Drought tolerance with high tissue water potential	
	(a)	Maintenance of water uptake
	(i)	increased rooting
	(ii)	increased hydraulic conductance
	(b)	Reduction of water loss
	(i)	reduction in epidermal conductance
	(ii)	reduction in absorbed radiation
	(iii)	reduction in evaporative surface.

1. Drought Escape

Two features of desert ephemerals that are important in drought resistance are-

I) Rapid phonological development.

II) Developmental plasticity.

I) Rapid phonological development

Ability to produce flowers with a minimum of vegetative structure enables them to produce seeds on a limited water supply.

II) Developmental plasticity

This feature enable the plants to produce an abundance of vegetative growth, flowers and seeds in seasons of abundant rain, enables the desert ephemerals to both escape drought and survive long periods without rain.

In crop plants, the greatest advance in breeding for water limited environment is achieved by a shortening of life cycle, thereby allowing the crops to escape drought. Therefore, there is a strong consistent negative correlation between grain yield and days to first ear emergence and 40-90% variation in wheat yield under drought condition was accounted for by earliness. In wheat it was observed that drought resistance is greater in early lines than late ones even at the same intensity of drought. However, under adequate water supply, yield is often positively correlated with maturity date in determinate annual crops such as maize, sorghum and sunflower.

An important aspect of developmental plasticity is the ability of plants to transfer assimilates accumulated prior to seed-filling to the grain during the seed filling stage. It was also suggested that when water supply is adequate only a small proportion of grain dry weight comes from the store of prior assimilate in the stems and roots, but when stress occurs in the seed filling stage, an increased proportion of the prior assimilate is transferred to the seed.

To achieve the developmental plasticity, plants frequently have an indeterminate habit. This is an important survival mechanism in that it enables the large amounts of seed produced in wet years to carry the species through prolonged drought periods.

Selection of rapid phonological development is the most rewarding approach in breeding for drought resistance in crops. In cereals, drought resistance varieties of wheat and barley flowered early than the others. However earliness is often negatively correlated with yield in year of adequate rainfall.

2. Drought Tolerance at High Tissue Water Potential

Ability of the plant to endure periods of drought by maintaining high tissue water potential. This mechanism is also called as drought avoidance.

To maintain a high water status during a period of high evaporative demand / or increasing soil water deficit, the plant has two options. It must either reduce the water loss or maintain its supply of water.

A. Reducing Water Loss

i) Increased pubescence.

ii) Increased leaf waxiness.

B. Maintenance of water uptake

i) Deeper root system.

ii) Hydraulic conductance of plants (increasing either the diameter of xylem vessels or their numbers).

3. Drought Tolerance at low tissue water potential

It is the ability of the plant to endure periods of drought and endure low tissue water potentials.

Distinguish between Biotic & Abiotic Stress

Biotic stress	Abiotic stress
1. Biotic stress include living organism. e.g. insect, pest, bacteria, fungi etc.	1. Abiotic stress include physical factors of environment. e.g. Temperature, moisture, wind, soil salinity and alkalinity etc.
2. The effect of biotic stress is changeable.	2. The effect of abiotic stress is stable.
3. The effect of biotic stress is density dependent.	3. Density independent.
4. Directly related to stress.	4. Indirectly related to stress.
5. Generally man can control it such as spraying, insecticides in case of insect.	5. Generally man can not control it. e.g. high temperature beyond the control of stress.